An evaluation of Scottish woodland grant schemes using site suitability modelling

***Title page with author details**

AN EVALUATION OF SCOTTISH WOODLAND GRANT SCHEMES USING SITE SUITABILITY MODELLING

Haydn J.D. Thomas*[,a,] James S. Paterson[a,] Marc J. Metzger[a] & Louise Sing[a,b]

*Corresponding Author:

Email: haydn.thomas@ed.ac.uk

Telephone: +44 (0)131 650 8734

a: University of Edinburgh, Crew Building, Alexander Crum Brown Road

EH9 3FF

b: Forest Research, Northern Research Station, Roslin, Midlothian EH25 9SY

Research Highlights

- We evaluate woodland expansion since 1989 using site suitability modelling.
- Local climate will constrain establishment or growth for unsuitable species.
- 88-97% of new woodland is located on suitable sites; this has improved over time.
- Higher suitability is concurrent with increased emphasis on ecological modelling.
- Forester use of modelling remains low; greater emphasis is placed on experience.

AN EVALUATION OF SCOTTISH WOODLAND GRANT SCHEMES USING SITE SUITABILITY MODELLING

1 INTRODUCTION

The Scottish Government has set out policy to increase woodland from 18% of land cover towards 25% by 2050, requiring the creation of approximately 10,000 hectares of woodland per year (Scottish Executive, 2006; WEAG, 2012). Much of this expansion will take place on private land but be publicly subsidised through woodland grant schemes (Sing et al., 2013). Subsidies are justified by the social and environmental benefits of woodland, including habitat restoration, carbon storage and recreation (FCS, 2009). However, these benefits vary by woodland type and over woodland lifetime, and are not necessarily guaranteed (van der Horst and Gimona, 2005). Despite this, there has been very little evaluation of woodland grant schemes, primarily due to the long time scales associated with woodland growth (Thomas et al., 2015). To account for the time-lag between planting and longer-term woodland benefits, we assess whether modelled site conditions, particularly climate, will constrain growth or establishment for woodland planted over the last 25 years in the Lochaber Forest District, Scotland.

1.1 Background and Context

1.1.1 Woodland Grant Schemes in Scotland

Approximately one third of woodland in Scotland is managed on behalf of the public by the UK Forestry Commission (FC, 2015). In these woodlands, decisions are guided by benefits arising to the public as a whole. However, two thirds of Scottish woodland is privately owned and the majority of future expansion is expected to take place on private land (Sing et al., 2013). In this case, decisions are largely shaped by private benefits accruing to landowners, even though additional public benefits arise as a result (Urquhart et al., 2010). Grant schemes address this market failure by offering incentives to create woodlands that generate social and environmental benefits (FCS, 2010). Grants contribute to planting costs, with additional payments available for woodland expansion on agricultural land. There have been six woodland grant schemes in Scotland since grants replaced tax incentives in 1988 (Table 1). At present, grants are provided through the Scottish Rural Development Programme (SRDP), now in its second stage.

An estimated 89.5% of private woodland creation in Scotland from 1992-2001 would not have occurred without grant aid, though this varies by scheme (CJC Consulting, 2002). Grant structures have also been instrumental in determining new woodland type (Lawrence and Edwards, 2013). However, planting rates remain well below those of the 1980s, and are falling short of targets (Scottish Government, 2010; Wilson, 2011). Multi-functional, native woodland is also now favoured over commercial conifer plantation, such that softwood production is predicted to fall sharply after 2030 (Slee, 2005; WEAG, 2012; FC, 2014a).

Table 1: Woodland Grant Schemes in Scotland

Woodland Grant Scheme	Period
Woodland Grant Scheme 1 (WGS1)	1988 - 1991
Woodland Grant Scheme 2 (WGS2)	1991 - 1994
Woodland Grant Scheme 3 (WGS3)	1994 - 2003
Scottish Forestry Grant Scheme (SFGS)	2003 - 2006
Scottish Rural Development Plan (SRDP) 1	2007 - 2014
Scottish Rural Development Plan (SRDP) 2	2014 - 2020

1.1.2 Woodland Suitability

The limited evaluation of woodland grant schemes to date appears to be particular to forestry, since similar agricultural schemes have received significant attention (Kleijn and Sutherland, 2003; Lahmar, 2010; Pe'er et al., 2014). One major difference is the associated timescales, since it can take decades to centuries for woodland to reach maturity (Clegg & Co., 2002). However, it may also reflect the infancy of methodologies and low priority for evaluation (Aronson et al., 2010). One approach that takes these limitations into account is the evaluation of site suitability, since woodlands that are unsuited to local climate (Ennos et al., 1998) or soils (Wilson et al., 2005) exhibit low growth rates or fail to establish entirely (Lee et al., 2002). In woodlands planted in Scotland between 1992-2001, CJC Consulting (2002) found that climatic factors accounted for approximately one fifth of heavy losses. Similarly, inappropriate species selection for local climate has been recognised anecdotally as contributing to the failure of several woodland expansion projects, though evidence for this is limited (Ennos et al., 1998; Gordon Patterson pers. comm. 16/07/14). While damage from extreme weather events is unavoidable, the extent to which temperature, precipitation and exposure variables are formally considered in selection of woodland species or seed provenance is unclear.

1.1.3 Ecological Suitability

Ecological suitability here refers to the climatic and edaphic suitability of sites for tree species. Formal assessment of ecological conditions as part of the woodland planning processes is strongly encouraged in Scotland. Many priority areas for forestry, notably the Scottish Highlands (Towers et al., 2006), experience cold annual temperatures, high precipitation, and strong winds (Mayes and Wheeler, 2013). Furthermore, basing species selection on existing woodland communities is often impossible due to a legacy of intensive land use that has heavily modified vegetation communities (Barnes and Pregitzer, 1982; Ennos et al., 1998; Quine et al., 2002). Site assessment is aided by land designation and local Forest and Woodland Strategies, which indicate priority areas for forestry based on site suitability, existing land use and community impacts, among other factors (FCS, 2010). However, evidence from Wales suggests that designations are often overruled (Wynne-Jones, 2013). Decision support tools such as the Forestry Commission's 'Ecological Site Classification' (ESC) are also actively promoted in woodland planning and are used by approximately one third of private foresters in the UK (Stewart et al., 2013). In the Scottish Highlands, ESC outputs or similar evidence are now required under the SRDP to justify woodland creation in marginal sites (FCS, 2012). However, the impact of this is unknown. Understanding whether ecological conditions will limit woodland benefits, and how this is accounted for in land use planning, would therefore greatly aid the effective design of future policy and grant scheme structures.

1.2 Study Aims

We use existing methods of spatial analysis and qualitative research to examine the extent to which ecological suitability may constrain woodland creation in the Lochaber Forest District, Scotland. We perform a post-hoc assessment of site suitability using ESC methodology to investigate whether grant-funded woodland expansion since 1989 has been appropriate for site conditions. We further investigate the role of ecological suitability and modelling tools in the woodland creation planning process through interviews with key stakeholders.

2 METHODS

2.1 Study Area

The study was carried out in the Lochaber Forest District in the Western Highlands of Scotland (Figure 1). Lochaber has a mountainous landscape, with land use dominated by sport-hunting estates and forestry (FCS, 2011). In 2011 the total forest area in Lochaber was 83,877 hectares, accounting for 17% of land area (FC, 2012). The dominant woodland type is conifer (56%), mainly *Picea sitchensis*. Successive woodland inventories indicate that woodland area has increased by 6,253 hectares (8%) since 1998 (FC, 2015). Grant scheme approvals account for 6% of woodland expansion under the SRDP. Woodland planning is primarily carried out by a small number of forestry agents and monitored by Forestry Commission Scotland, The Highland Council and Scottish Natural Heritage (SNH).

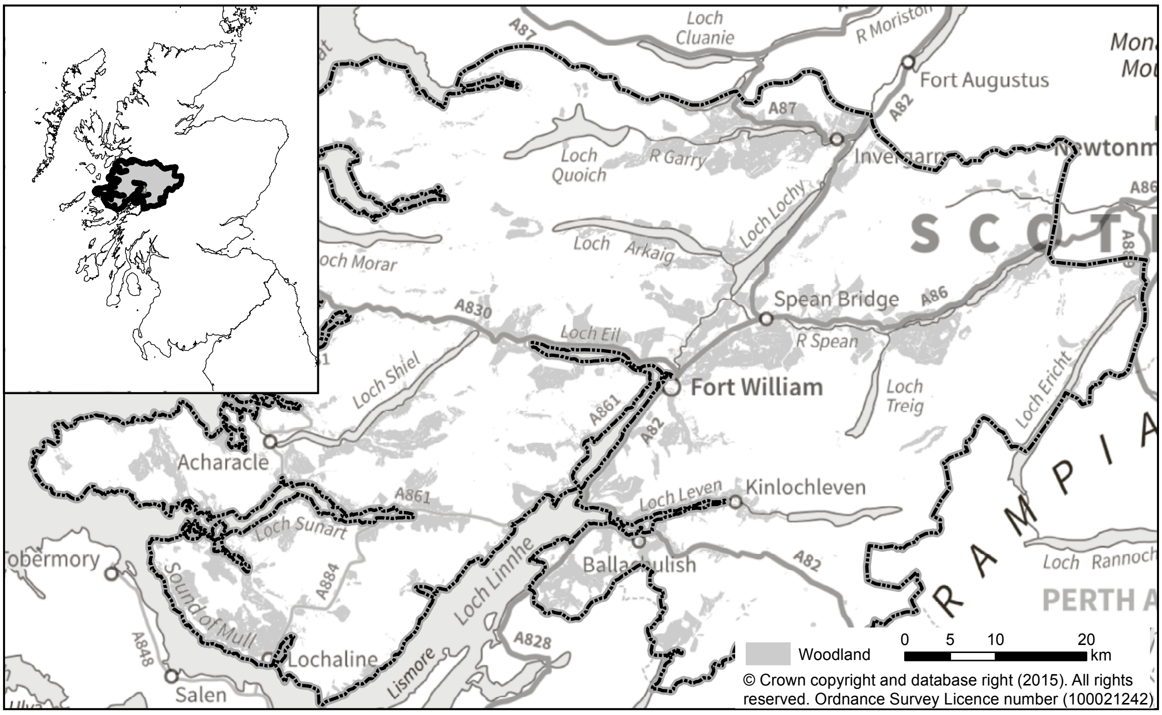


Figure 1: Map of Lochaber Forest District indicating position within Scotland and woodland area.

Table 2: Ecological variables in Lochaber (FCS, 2011)

Climate	Atlantic maritime climate: cool, wet winters and warm, wet summers. Rainfall approximately 2,000 mm/yr.
Water	District dominated by the Great Glen, including major catchments of Glen Garry, Glen Spean and Glen Nevis. Year-round snow on Ben Nevis stabilises water balance.
Soils	Predominantly upland peats[1] with iron-pans and low-nutrient deep peats in the uplands due to heavy rainfall. Peaty-gleys and forest brown-earths on lower slopes.
Habitats	Nationally important Atlantic oakwoods, upland birch woodlands and remnant pine forest, in addition to open-moorland and mountaintop environments.

2.2 Spatial Evaluation of Climatic Suitability

[1] Soil classification based on the 1:250,000 Soil Survey of Scotland National Soil Inventory (The Macauley Institute for Soil Research, 1984).

2.2.1 Data collection

We collated records of woodland creation in Lochaber from publicly available datasets covering grant schemes between 1989-2014 (FC, 2014b; Supplementary Materials). Scottish Forestry Grant Scheme (SFGS) data were excluded because we could not distinguish woodland creation from other forestry activities. Forestry Commission Scotland provided additional species composition mapping under the SRDP. This information was unavailable for previous grant schemes beyond distinction between broadleaf (including *Pinus sylvestris* as an 'honorary broadleaf') and conifer woodland.

2.2.2 Climate suitability modelling

We assessed the climatic suitability of site location and species selection using suitability maps generated using ESC methodology at a resolution of 250m^2 (Bathgate, 2011). ESC matches four climatic and two edaphic variables with the ecological requirements of tree species using a knowledge-based model (Table 3; Pojar et al., 1987; Pyatt et al., 2001). A detailed description of ESC methodology is outlined by Pyatt and Suarez (1997) and Pyatt et al. (2001). Since it was not possible to collect soil samples from study sites, soil variables were not included in spatial evaluation. A separate analysis was conducted for edaphic suitability.

We selected the most abundant tree species in the district to model suitability scores (Supplementary Materials). To account for unknown species composition, we generated broadleaf and conifer species-assemblage maps based on the weighted composition of native woodland under the SRDP (broadleaf woodland), and *Picea sitchensis* for conifer woodland. We generated output suitability raster maps for each species and species-assemblage. Every pixel was assigned a suitability score between

0 and 1 (<0.30 – Unsuitable; 0.30-0.50 – Marginal; 0.50-0.75 – Suitable; >0.75 – Very Suitable, based on Pyatt et al., 2001).

Table 3: Variables used in ESC methodology (Pyatt et al., 2001)

Variable	Description	Included in model
Accumulated Temperature	Number of degree days per year >5℃, representing warmth required for growth.	Yes
Moisture Deficit	Difference between summer evaporation and rainfall, representing water availability.	Yes
Windiness	Based on ‘Detailed Aspect Method of Scoring’ (Quine and White, 1994), representing wind strength and frequency.	Yes
Continentality	Based on the Conrad Index (Birse, 1971), representing seasonal climate variation.	Yes
Soil Moisture	Based on soil type, representing moisture availability.	No
Soil Nutrients	Estimated from soil characteristics and vegetation layer, representing nutrient availability.	No

2.2.3 Site suitability assessment

Woodland creation polygons were overlaid on output suitability maps to generate suitability scores for each woodland. Pixels were counted if >50% lay inside the woodland polygon. Scores were weighted by species composition to provide an overall suitability score for each polygon. We conducted two analyses, i) SRDP only, using detailed species composition, and ii) all grant schemes, using species assemblages. Differences between approaches and woodland grant schemes were tested using ANOVA and t-tests. We examined within-woodland variability by examining the proportion of woodland area with a suitability score <0.3. Woodland location was tested for randomness by comparing 10,000 randomly sampled pixels with 10,000 random woodland pixels using two-tailed t-tests. Spatial analysis was conducted in QGIS 2.4 (QGIS, 2014). Statistical calculations were performed using

Microsoft Excel Version 14.4.8 (Microsoft, 2011) and R Version 3.2.0 (R Development Core Team, 2015).

2.3 Evaluation of Edaphic Suitability

Edaphic suitability was investigated at the landscape scale by generating suitability scores for soil moisture and soil nutrients using the online ESC tool (Forest Research, 2015). Soil inputs were based on the National Soil Inventory at a resolution of $5km^2$ (Lilly et al., 2010). Site location was based on the grid reference or central coordinates of woodland sites.

2.4 Role of ecological suitability in woodland planning

We investigated the role of ecological suitability and modelling in decision-making through semi-structured interviews with key stakeholders. Interviews also provided a means to explore spatial findings in more depth (Berg, 2004). We limited scope to forestry agents, and stakeholders from the three mandatory decision making bodies (Table 4) since we considered these to exert greatest influence over planning. Together, interview respondents had worked on all SRDP applications in the region. We identified forestry agents from grant applications and discussions with Forestry Commission Scotland. All but two forestry agencies operating in the area took part in interviews. Landowners were not included in interviews. We also interviewed representatives from Forest Research on the development and use of ESC. Fourteen interviews were conducted in total, representing five stakeholder groups. Interviews were carried out face-to-face or by phone and were transcribed in full.

Table 4: Stakeholder groups represented in interviews

Stakeholder Group	Description	No. of Interviews
Forestry Agents	Professional forester employed by landowner to manage woodland creation.	6
Forestry Commission	Responsible for National Forest Estate and approval of woodland expansion applications.	4
Forest Research	Conduct a range of forestry research, including the development of ESC.	2
Highland Council	Statutory consultee for woodland creation, representing local communities.	1
Scottish Natural Heritage	Statutory consultee for woodland creation, representing conservation, habitat and landscape interests.	1

3 RESULTS

3.1 Climatic suitability of new woodland

3.1.1 Scottish Rural Development Plan (2007-2014)

A total of 53 woodland creation applications had been approved in Lochaber under the SRDP at the time of research (August 2014). 47 applications were for native woodland, 4 for productive conifer, and 2 for mixed woodland. The majority of applications relied on direct planting, with only six woodlands using natural regeneration.

Based on species composition maps, 83% of new woodlands were climatically suitable or very suitable. Only one application was unsuited to local climate, accounting for 3% of new woodland area, though six applications (12% of area) were unsuitable within one standard deviation (Figure 2). *Alnus glutinosa* and wet woodland species were least suited to sites with mean suitability scores of 0.37 and 0.48 respectively, in line with previous findings by Ogilvy (2004). However, these may be located in microclimates that are inadequately modelled by ESC. *Picea sitchensis* (0.78) and *Betula spp*. (0.71) woodlands were most suited to sites. Woodland locations differed significantly ($p<0.01$) from random spatial sampling.

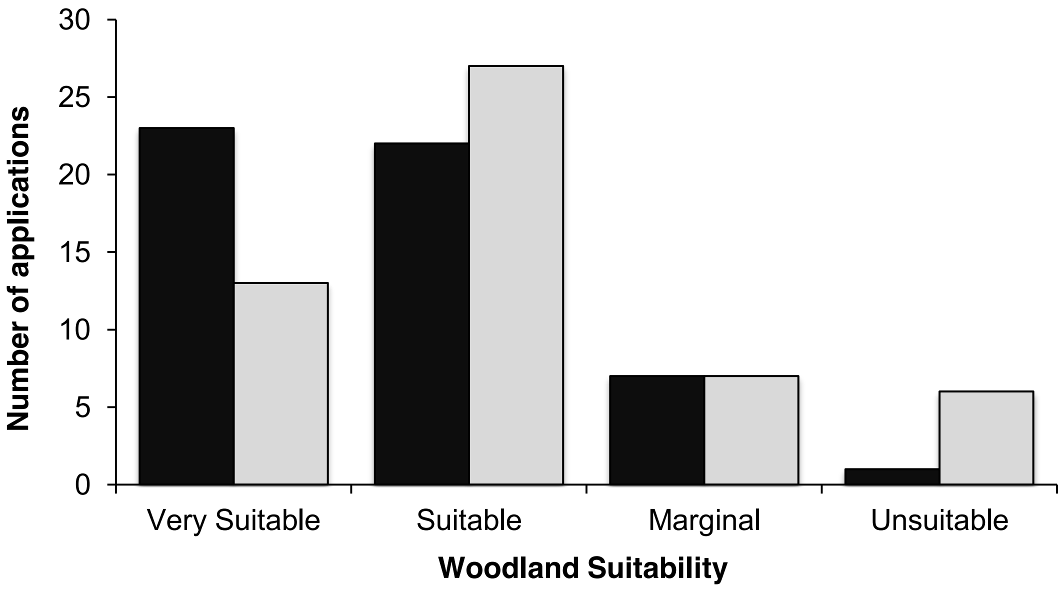


Figure 2: Suitability of woodland planted under the Scottish Rural Development Plan. Black bars represent mean woodland scores. Grey bars represent scores within one standard deviation of the mean.

3.1.2 All woodland grant schemes (1989-2014)

Based on estimated species assemblages, 76.5% of woodlands were climatically suitable or very suitable. Of 385 grant applications, only five were unsuited to climatic conditions (0.7% of woodland area). However, taking account of within-woodland variability, 8% of woodland area (0-12% by scheme) was unsuited to climatic conditions (Figure 3). There was a statistically significant increase in suitable area from 88% under WGS3 to 97% under the SRDP (p<0.05).

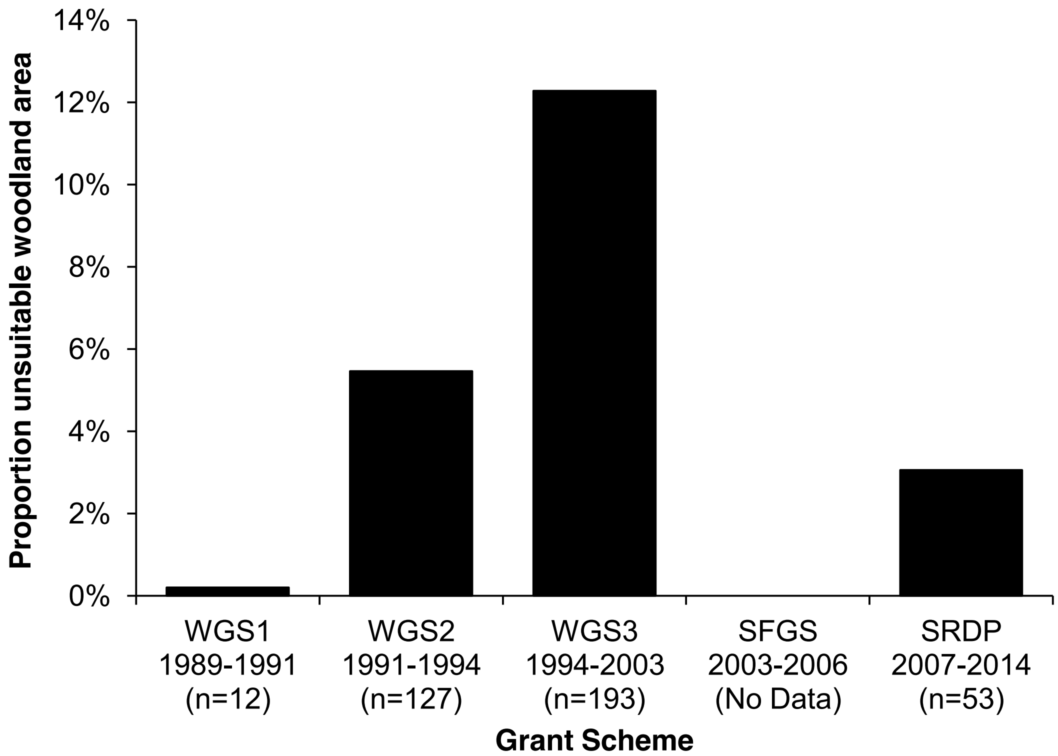


Figure 3: Proportion of climatically unsuitable woodland planted under Scottish Woodland Grant Schemes (1989 – 2014). Woodland is considered climatically unsuitable if it has a suitability score of <0.3. Data not available for the SFGS.

There was no significant change in the mean climatic suitability of woodlands across all applications (Figure 4). In general conifer woodland was located in more climatically suitable areas than native woodland, though this difference decreased over time (p<0.01). Climatic suitability of native woodland decreased between 1991 and 2003 (p<0.05), but there was no significant change under the SRDP. There was close correspondence between suitability for the SRDP under both modelling approaches.

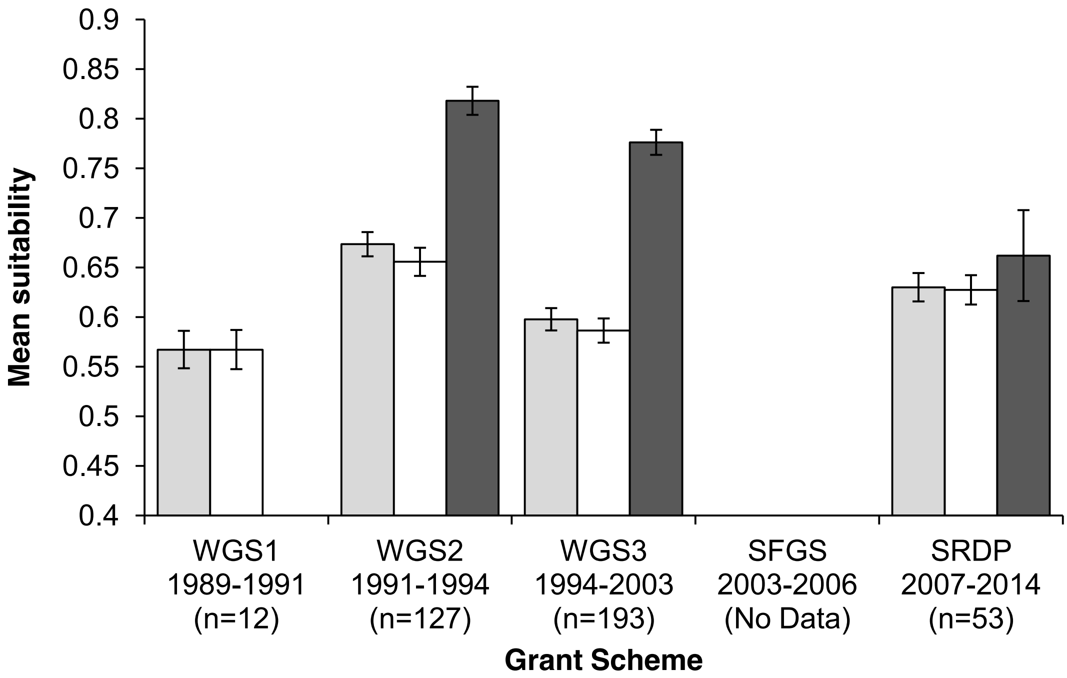


Figure 4: Mean climatic suitability of Scottish Woodland Grant Schemes. Light grey bars represent mean suitability for all woodlands, white bars broadleaf woodland, and dark grey bars coniferous woodland. Error bars indicate one standard error. Data not available for the SFGS.

3.2 Edaphic Suitability of New Woodland

48% of applications (44% of woodland area) were edaphically suitable or very suitable. 51% of applications (56% of area) were marginal, while only two applications (1%, <0.01% of area) were unsuitable. However, due to the coarse resolution of underlying soil data only a small number of unique suitability values were obtained. This prevented the generation of meaningful output distributions

(Supplementary Materials). As such, we have low confidence that ESC outputs adequately reflect site characteristics.

3.3 Influence of Climate Suitability on Woodland Planning

3.3.1 The decision-making process for woodland expansion

A four-stage conceptual model of the woodland expansion decision-making process is outlined in Figure 5. While interviews focused on ecological suitability, it was clear that decision-making is also contingent on economic, landscape, and community considerations, among other factors. This model applies specifically to the woodland planning process, and does not include motivations for woodland vis-à-vis other land uses (see Lawrence and Dandy, 2014), or activities taking place once approval has been granted.

Stage 1: Suitability for Woodland

The first stage of the decision-making process is an initial, high-level site analysis. Woodland is often of low priority to landowners and as such woodland may only be considered if no other land use is possible.

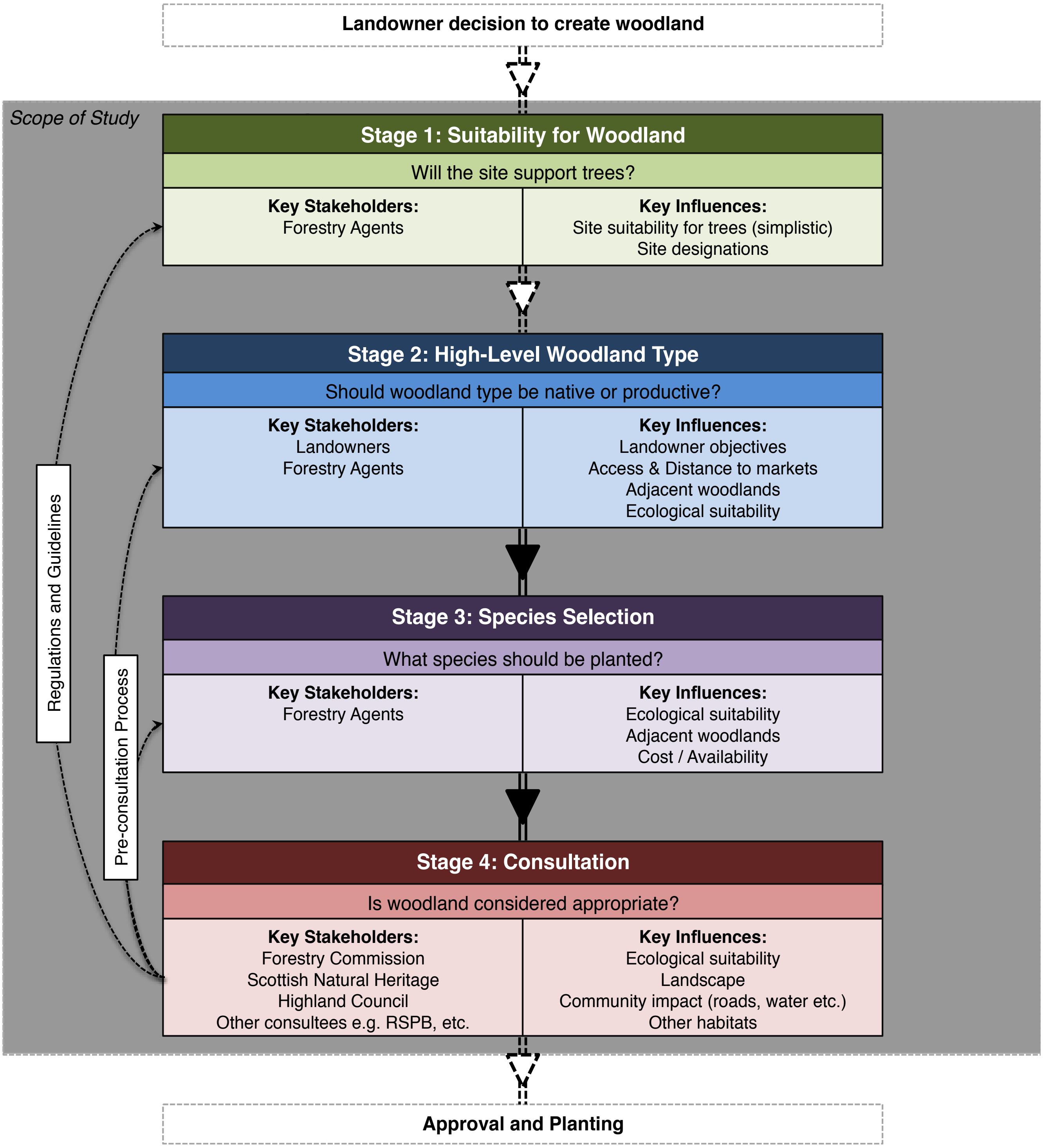


Figure 5: Conceptual model of the woodland planning process. Planning goes through four stages i) consideration of site suitability, ii) consideration of woodland type, iii) species selection, and iv) public consultation. Key stakeholders and influences on each stage are outlined, in addition to links between stages arising from regulations and pre-consultation.

"People think 'we've got a spare patch of land' and it's usually a peat bog. It can't be used because it's a bog but that also means it's not suitable for trees…nobody is interested in that land, not even a forester."

Forestry Agent

Initial evaluation may take the form of a brief site visit or desktop analysis, but rarely involves detailed assessment. Suitability is primarily determined by edaphic considerations, most notably the presence of peat, but also incorporates factors such as land designation and access.

Stage 2: High-Level woodland type

Should the site be considered suitable for woodland, design is usually based on selection of either native or productive woodland. Although some agents argued that this dichotomy need not occur, for example by planting *Pinus sylvestris* as a commercial crop, decisions are nonetheless dependent upon objectives rather than ecologically suitable species.

"In terms of objectives it's normally native or commercial. We might be able to influence which one they think about but the objectives are usually financial. They'll want to know how they can make money from woodland."

Forestry Agent

Forestry agents repeatedly emphasised the importance of grant rates in determining woodland type. Commercial woodland would require investment by the owner, in contrast to the immediate return of native woodland grants. As such, native woodlands made up the majority of new planting. In some cases, agents stated that owners had revised plans for commercial woodland upon receiving financial estimates, instead planting native species. Market considerations such as international demand and timber production forecasts were rarely mentioned. Some owners were also described as having a strong conservation ethic or the desire to leave a positive legacy for future generations, though this was rare.

Stage 3: Species Selection

Once woodland type has been identified, species are selected from the subset of available native or productive species, according to site suitability. This is primarily dependent upon soil characteristics, local climate, and existing vegetation. Information is gathered through site surveys, with varying use of ecological modelling tools such as ESC.

Vegetation surveys were considered the best indicator for species selection where existing woodland was present. However, many stakeholders stated that heavy modification of upland environments meant that remaining vegetation communities were rarely informative of potential woodland. Consequently, both agents and the Forestry Commission viewed soil variables as the most useful indicator of site suitability. However, high variability in soil type within Lochaber was emphasised as a barrier to effective species selection. In contrast, climatic factors were considered of low importance except in microsites. Finally, the cost and availability of seed sources was stated to influence selection, with cheaper species such as *Betula spp*. favoured.

Stage 4: Consultation and Approval

All new woodland applications are subject to approval by the Forestry Commission, in addition to a 28-day public consultation period. Further approval is required from SNH and the Highland Council as statutory consultees. Woodland applications must demonstrate appropriate site and species selection. This necessarily goes beyond ecological variables and takes into account landscape, existing habitats, and community concerns such as access and water supply. Applications must be supported by evidence, including soil data, ESC outputs and landscape assessment.

While it is rare for applications to be rejected, this stage can cause significant delays. The approval process typically takes three to six months in the case of "good, well founded, appropriate applications", but potentially up to several years if modifications are required. This is partly due to resource limitations and partly due to insufficient supporting evidence. Delays were a cause of frustration to consultees, forestry agents and owners. It was felt that the application process was becoming more complex, linked to increasing grant value and regulation from various bodies. This was reflected by stakeholders on both sides of the approval process, though was seen not as an issue of purpose, but of process.

"I don't think there's a problem with what they're trying to do in the SRDP. It's just the way they have gone about it, it's very complicated and time consuming to do."

Forestry Agent

There was some evidence that pre-consultation and the use of the Highland Forests and Woodlands Strategy (Highland Council, 2006) were improving the process by highlighting potential issues early on. However, some forestry agents saw this as excessive interference on behalf of external bodies.

3.3.2 Use of Ecological Site Classification in the Planning Process

All forestry agents had some experience of ESC, though fewer than half used it regularly. ESC analysis was mainly implemented in the species selection (Stage 3) and approval (Stage 4) stages of the decision-making process, and had four major uses.

i. **Informing species choice**. Analysis of ecological parameters enabled the identification of appropriate species for a given site. While the intended purpose of ESC, few agents stated that they used it in this way.

ii. **Supporting decision-making.** More commonly, agents stated that ESC was used to confirm decisions already made.

> *"I have used some of the information to almost back up some of my decisions rather than the other way round, rather than using it to dictate."*
>
> Forestry Agent

While generally considered reliable, ESC outputs were commonly dismissed if they did not support the agents' decisions. Agents referred to limitations of ESC, or argued that site indicators such as existing vegetation contradicted outputs. This relied heavily on the experience of foresters who "have been around a lot longer than ESC has". No instances where ESC outputs had altered woodland design were encountered.

iii. **Justifying applications.** Forestry agents used ESC to justify woodland applications to the Forestry Commission. This was particularly the case for larger projects, which facilitated higher budgetary and time requirements for analysis. However, there was some suggestion of selective use, whereby evidence was only supplied when outputs supported the application. Some also suggested that "you can bend or twist [ESC] to give out what you want", enabling outputs to be shaped by decisions, rather than vice-versa.

iv. **Assessing applications**. The use of ESC by the Forestry Commission to evaluate applications appeared to be influential, but not critical. There was a view that agents could be trusted, and that experience was valued above modelling. However, where sites were marginal, ESC outputs would be required to support applications, and would inform disputes over the selection of species or seed sources.

Overall, ESC was viewed as a useful but not essential "tool in the toolbox", though one with a number of limitations. These included high sensitivity to inputs, particularly soil nutrients, and the cost of gathering required data. While stakeholders acknowledged that ESC had improved over time, experience took precedence over modelling, both in the decision-making process and when assessing potential woodland sites.

"Modelling has its place… it's nice, it confirms something. But it doesn't tell you anything you didn't necessarily know already."

Forestry Agent

4 DISCUSSION

4.1 Climatic suitability of new woodland

The majority of grant-funded woodland expansion in Lochaber since 1989 has been climatically suited to site conditions. It is unlikely that current climate will is a major barrier to woodland establishment in Lochaber, and for most sites does not limit establishment or growth. Nevertheless, there is still evidence that unsuitable schemes are being accepted, albeit rarely, with 3-12% of new woodland considered unsuited to climatic conditions. Given the requirement for ESC outputs to justify marginal schemes (FCS, 2012), this suggests that evidence is either inappropriate or has been overruled based on local knowledge.

This analysis has assumed climate to be constant over woodland lifetime. However, climate has already changed in Scotland in the last 60 years (Werritty and Sugden, 2013), and Lochaber is predicted to experience warmer, wetter winters and drier summers over the next 30 years (Murphy et al., 2009). This will potentially decrease suitability for key species such as *Picea sitchensis* and *Pinus sylvestris* (Smout, 2006; Petr et al., 2015). Choosing species that are appropriate for future climates is therefore increasingly important, and is receiving much attention in both research (Berry et al., 2002; Broadmeadow, 2005; Ray et al., 2008; Ogden and Innes, 2009; Hanewinkel et al., 2012; Lindner et al., 2014) and in policy (Read et al., 2009; FC, 2011; FCS, 2015). Since 2011 ESC has also included indicative future climate scenarios at the landscape scale (Bathgate, 2011). However, we find little interview evidence that climate change considerations are yet a major factor in woodland planning and species selection among private consultants.

The study is also limited by a 250m^2 model resolution that cannot reflect the complexity of underlying ecological conditions. Microclimates such as sheltered valleys or riparian zones are therefore inadequately represented (Riitters et al., 1997). However, model resolution is higher than alternative models such as WorldClim (Hijmans et al., 2005) and the same as that available to woodland planners. It is unlikely that higher resolution climate modelling would greatly affect results since analysis is constrained by species composition data, which are either unavailable or only available at the whole-woodland scale. Finally, ESC methodology is based on expert-opinion and may inadequately represent site suitability. Nevertheless, site quality judgements are based on empirical observations and experimental trials, while model inputs such as windiness have been shown to perform well in complex landscapes (Suárez et al., 1999; Ray, 2001; Wilson et al., 2001, 2005).

4.2 The Influence of Ecological Suitability on Woodland Planning

We find strong evidence that ecological suitability is accounted for in site, species and seed provenance selection within the woodland planning process. Spatial evaluation indicates that the vast majority of woodland has been located in climatically suitable areas. Given that woodland location is non-random, this indicates that climate is being taken into account, either through the experience of foresters, or formally within the planning process. This is supported by interview evidence that ecological considerations inform both species selection and planning approvals. However, we find that ecological suitability appears to play a minor role in regards to woodland type, which is more greatly influenced by grant scheme structure (Dandy, 2012). This aligns with previous indications that grant rates are the greatest determinant of woodland type in Scotland (Mindspace, 2010; WEAG, 2012; Lawrence and Edwards, 2013). Native woodland has comprised 95% of woodland creation in Lochaber despite high suitability and industry pressure for productive forestry. While we recognise the numerous benefits of native woodland (Thomas et al., 2015), this nevertheless conflicts with the Scottish Government's ambition that 60% of new woodland should be for softwood production (FCS, 2009; WEAG, 2012).

We find some evidence that woodland suitability has improved as a result of stronger emphasis on ESC under the SRDP (FCS, 2012). This is most likely due to modification or rejection of the most unsuitable applications since overall woodland suitability has remained constant. ESC may also have increased transparency of assessment, particularly for non-forestry stakeholders (Nilsson et al., 2008; Chetcuti et al., 2009). However, improvements could have arisen due to increased length and scrutiny of the consultation process under the SRDP. We also found little evidence in interviews that use of or attitudes towards ESC had changed among forestry agents as a result of new requirements. Nevertheless, some held a view that requirements had formalised ecological criteria within decision-making processes. This may also reflect a cultural shift in woodland planning, from modifying sites to modifying species selection (Ray and Broome, 2001; Slee, 2007).

Finally, the increased use of ESC mirrors a rise in decision support and modelling tools in many field-based professions (Clare and Ray, 2001; Bernard and Prisley, 2005; Reynolds et al., 2007). We found similar conflicts to those identified by Stewart et al. (2013) between computer-based decision support tools and forestry experience. ESC offers an empirical approach to assessing suitability and is a valuable training tool (Chetcuti et al., 2009; Stewart et al., 2013). However, it strongly relies on the ability of the forester to 'read' the site conditions (Ray and Broome, 2001). As such, some agents believed reliance on modelling to be symptomatic of a decline in forestry expertise and outdoor experience (Robbins, 2003; Leslie et al., 2006). Indeed, some argue that essential forestry skills will be lost if decision-making is reduced to a 'tick-box' process (Lawrence and Edwards, 2013). This study finds no evidence for this, at least within the woodland planning process. Professional forestry agents continue to be integral to woodland planning, which remains heavily reliant on local knowledge and expert judgment. Given that 90% of projects in Lochaber are agent-led, consistent with figures for the whole of Scotland (CJC Consulting, 2002), it is surprising that forestry agents and have been largely overlooked in research to date (Hujala et al., 2007; Lawrence et al., 2010; Buijs and Lawrence, 2013).

4.3 Additional influences on suitability

4.3.1 Soils

Soil is a major factor in determining site suitability for woodland, incorporated into both ESC methodology and the woodland expansion decision-making process (Wilson et al., 2005; FCS, 2012). Interviews findings indicate that soil plays a key role in determining site suitability, particularly due to high variability within and across sites. An absence of high resolution soil data is also commonly recognised as a constraint on suitability modelling (Quine et al., 2002; Bailey et al., 2006). As such, we argue that local soil sampling is critical, and ESC should not be used to determine edaphic suitability without local inputs.

4.3.2 Management

Management factors, particularly grazing and weed growth are perceived as the greatest threats to new woodland establishment in Scotland (Newton et al., 2001). Deer grazing is a major issue in Scottish woodland management, and is a significant barrier to both regeneration of existing woodland and woodland expansion (Staines, 1995; Gill and Morgan, 2010; Tanentzap et al., 2013). While only one study (CJC Consulting, 2002) has evaluated the role of management in grant scheme success, findings are broadly in line with perceptions, with weed growth and grazing the most common threats to new woodlands. We further emphasise the importance of woodland management by demonstrating that, in the majority of cases, success does not appear to be limited by current climatic suitability.

4.3.3 Implementation

We found some evidence that woodland expansion may be limited by logistics and implementation. Difficulties in obtaining local seed sources and planting moratoriums due to pathogens delay or alter schemes after approval (Newton et al., 2001; Spracklen et al., 2013; Fraser et al., 2015). Such threats may become more widespread as the climate warms (Sturrock et al., 2011). Furthermore, deviation between planning and implementation was commonly cited as a reason for failure of woodland expansion projects. Reasons posited for this included staff cuts, fewer training opportunities and cost saving. Funding gaps between grant schemes also undermine confidence and place additional pressure on planning, training and recruitment. This is evidenced by the hiatus in woodland creation between the closure of the SFGS in 2006 and initiation of the SRDP in 2007 (FC, 2014b). Although the implications of grant scheme irregularity have been well documented (Lawrence and Edwards, 2013; Osmond and Upton, 2012; WEAG, 2012), we argue that these disruptions exert considerably wider-reaching pressures across the supply-chain.

5 CONCLUSIONS

This paper presents an evaluation of woodland grant schemes in Lochaber using site suitability modelling. We find that the majority of grant-funded woodland expansion since 1989 has been suited to site conditions. Moreover, the proportion of suitable woodland has increased from 88% to 97% under the latest woodland grant scheme. This may be due in part to a formalisation of site selection criteria through ecological modelling and a return to the philosophy of matching species to sites. However, it may also be driven by the increased scrutiny of the consultation process, suggesting a potential trade-off between site suitability and administration cost. Overall, it is unlikely that current climate will limit woodland growth and benefits in Lochaber under existing practice. While climate change may alter the suitability of woodland sites, this does not yet appear to strongly influence private woodland design. Emphasis should also be placed on woodland management, particularly in relation to grazing exclusion, in securing woodland grant scheme success.

Acknowledgements

We are grateful to Forest Research and Forestry Commission Scotland for helping to conceive this study, to all interview participants for their time and clarity, and to S. Bathgate for generating ESC outputs and answering many questions. Special thanks to the Highland Conservancy for providing detailed information on recent grant schemes. We also thank Dr D. Edwards, Dr A. Gimona, D. Ray, M. Smith, and Dr D. van der Horst for additional input and guidance on research methods and analysis. Finally, we would like to thank two anonymous reviewers for their insightful comments and suggestions.

6 REFERENCES

Aronson, J., Blignaut, J.N., Milton, S.J., Le Maitre, D., Esler, K.J., Limouzin, A., Fontaine, C., de Wit, M.P., Mugido, W., Prinsloo, P., van der Elst, L., Lederer, N., 2010. Are Socioeconomic Benefits of Restoration Adequately Quantified? A Meta-analysis of Recent Papers (2000-2008) in Restoration Ecology and 12 Other Scientific Journals. Restor. Ecol. 18, 143–154.

Bailey, N., Lee, J.T., Thompson, S., 2006. Maximising the natural capital benefits of habitat creation: Spatially targeting native woodland using GIS. Landsc. Urban Plan. 75, 227–243.

Barnes, B., Pregitzer, K., 1982. Ecological forest site classification. J. For. 80, 6.

Bathgate, S., 2011. Ecological Site Classification. Forest Research.

Berg, B., 2004. Qualitative research methods for the social sciences, Volume 5. ed. Boston: Pearson.

Bernard, A.M., Prisley, S.P., 2005. Digital Mapping Alternatives: GIS for the Busy Forester. J. For. 103, 163–168.

Berry, P.M., Dawson, T.P., Harrison, P.A., Pearson, R.G., 2002. Modelling potential impacts of climate change on the bioclimatic envelope of species in Britain and Ireland. Glob. Ecol. Biogeogr. 11, 453–462.

Birse, E.L., 1971. Assessment of climatic conditions in Scotland, 3: The bioclimatic sub-regions. Macauley Land Use Research Institute, Aberdeen.

Broadmeadow, M.S.J., 2005. Climate change and the future for broadleaved tree species in Britain. Forestry 78, 145–161.

Buijs, A., Lawrence, A., 2013. Emotional conflicts in rational forestry: Towards a research agenda for understanding emotions in environmental conflicts. For. Policy Econ. 33, 104–111.

Chetcuti, J., Knott, K., Smith, M., 2009. Incorporating ecological modelling into the planning of forest plans. Ecol. Networks Sci. Pract. 16, 89–96.

CJC Consulting, 2002. Impacts of the Woodland Grant Scheme and the Farm Woodland Premium Scheme in Scotland. Rep. Scottish Exec. Environ. Rural Aff. Dep. March 2002. www.cjcconsulting.co.uk/texts/scotexecwgsreport20.pdf.

Clare, J., Ray, D., 2001. A spatial model of Ecological Site Classification for forest management in Britain. Geogr. Inf. Euorope Integr. interopable, Interact. 93–111.

Clegg & Co., 2002. Evaluation of Woodland Creation in England Under the Woodland Grants Scheme and the Farm Woodland Premium Scheme. A Rep. to DEFRA For. Comm.

Dandy, N., 2012. Understanding Private Land-manager Decision-making: A Framework for Forestry. Forest Research.http://www.forestry.gov.uk/pdf/Understanding_land-manager_decision-making_Dandy2012.pdf/$FILE/Understanding_land-manager_decision-making_Dandy2012.pdf.

Ennos, R.A., Worrell, R., Malcolm, D.C., 1998. The genetic management of native species in Scotland. Forestry 71, 1–23.

FC, 2011. The UK Forestry Standard. For. Comm. Edinburgh. www.forestry.gov.uk/theukforestrystandard.

FC, 2012. NFI Woodland map 2011 Lochaber Forest District. For. Comm. Scotl.

FC, 2014a. 50-year forecast of softwood timber availability. For. Comm. http//www.forestry.gov.uk/pdf/50_YEAR_FORECAST_OF_SOFTWOOD_AVAILABILITY.pdf/$FILE/50_YEAR_FORECAST_OF_SOFTWOOD_AVAILABILITY.pdf.

FC, 2014b. Forestry Statistics 2014. For. Comm. Edinburgh. http//www.forestry.gov.uk/website/forstats2014.nsf/LUContentsTop?openview&RestrictToCategory=1.

FC, 2014c. Data Download [WWW Document]. URL http://www.forestry.gov.uk/datadownload (accessed 7.26.14).

FC, 2015. Forestry Statistics 2015 223.

FCS, 2009. The Scottish Government's rationale for woodland expansion. For. Comm. Scotland. http//www.forestry.gov.uk/pdf/ForestExpansion.pdf/$FILE/ForestExpansion.pdf.

FCS, 2010. The right tree in the right place. For. Comm. Scotland. www.forestry.gov.uk/pdf/fcfc129.pdf/$FILE/fcfc129.pdf.

FCS, 2011. Lochaber District Strategic Plan. For. Comm. Scotland, Edinburgh. http//scotland.forestry.gov.uk/managing/plans-and-strategies/forest-district-strategies 2011–2015.

FCS, 2012. Assessing Marginal Sites for New Native Woodland RDC - Rural Priority Applications. For. Comm. Scotl.

FCS, 2015. The Scottish Forestry Strategy: Progress Report (2014-2015) and Future Implementation (2015-2018). Forestry Commission Scotland.

Forest Research, 2015. Ecological Site Classification Version 4: Online Decision Support Tool [WWW Document]. URL http://www.forestdss.org.uk/geoforestdss/esc451.jsp#

Fraser, S., Mullett, M.S., Woodward, S., Brown, A. V, 2015. Between-site and -year variation in the relative susceptibility of native Scottish Pinus sylvestris populations to dothistroma needle blight. Plant Pathol. 1–11.

Gill, R.M.A., Morgan, G., 2010. The effects of varying deer density on natural regeneration in woodlands in lowland Britain. Forestry 83, 53–63.

Hanewinkel, M., Cullmann, D. a., Schelhaas, M.-J., Nabuurs, G.-J., Zimmermann, N.E., 2012. Climate change may cause severe loss in the economic value of European forest land. Nat. Clim. Chang. 3, 203–207.

Highland Council, 2006. Highland Forest and Woodland Strategy.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25, 1965–1978.

Hujala, T., Pykäläinen, J., Tikkanen, J., 2007. Decision making among Finnish non-industrial private forest owners: The role of professional opinion and desire to learn. Scand. J. For. Res.

Kleijn, D., Sutherland, W.J., 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? J. Appl. Ecol. 40, 947–969.

Lahmar, R., 2010. Adoption of conservation agriculture in Europe. Land use policy 27, 4–10.

Lawrence, A., Dandy, N., 2014. Private landowners' approaches to planting and managing forests in the UK: What's the evidence? Land use policy 36, 351–360.

Lawrence, A., Dandy, N., Urquhart, J., 2010. Landowners' attitudes to woodland creation and management in the UK: A review of current evidence. For. Comm.

http//www.forestry.gov.uk/pdf/Landowner_attitudes_evidence_review_final_2010.pdf/$FILE/Landowner_attitudes_evidence_review_final_2010.pdf.

Lawrence, A., Edwards, D., 2013. Prospects for new productive woodland in Scotland: insights from Stakeholders. A Rep. to For. Comm. Scotland. http//www.forestry.gov.uk/pdf/Lawrence_Edwards2013.pdf/$FILE/Lawrence_Edwards2013.pdf.

Lee, J.T., Bailey, N., Thompson, S., 2002. Using Geographical Information Systems to identify and target sites for creation and restoration of native woodlands: a case study of the Chiltern Hills, UK. J. Environ. Manage. 64, 25–34.

Leslie, A.D., Wilson, E.R., Starr, C.B., 2006. The current state of professional forestry education in the United Kingdom. Int. For. Rev. 8, 339–349.

Lilly, A., Bell, J.., Hudson, G., Nolan, A.., Towers, W., 2010. National Soil Inventory of Scotland 1 (NSIS_1): site location, sampling and profile description protocols (1978-1988). Tec. Bull. Macaulay Inst.

Lindner, M., Fitzgerald, J.B., Zimmermann, N.E., Reyer, C., Delzon, S., van der Maaten, E., Schelhaas, M.J., Lasch, P., Eggers, J., van der Maaten-Theunissen, M., Suckow, F., Psomas, A., Poulter, B., Hanewinkel, M., 2014. Climate change and European forests: What do we know, what are the uncertainties, and what are the implications for forest management? J. Environ. Manage. 146, 69–83.

Mayes, J., Wheeler, D., 2013. Regional weather and climates of the British Isles-Part 1: Introduction. Weather 68, 3–8.

Microsoft, 2011. Microsoft Excel. [Computer Software] Redmond, Washington.

Mindspace, 2010. Farmers research study, Report to Forestry Commission Scotland.

Murphy, J.M., Sexton, D.M.H., Jenkins, G.J., Boorman, P.M., Booth, B.B.B., Brown, C.C., Clark, R.T., Collins, M., Harris, G.R., Kendon, E.J., Betts, R.A., Brown, S.J., Howard, T.P., Humphrey, K.A., McCarthy, M.P., McDonald, R.E., Stephens, A., Wallace, C., Warren, R., Wilby, R., Wood, R.A., 2009. UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter.

Newton, A., Stirling, M., Crowell, M., 2001. Current Approaches to Native Woodland Restoration in Scotland. Bot. J. Scotl. 53, 169–195.

Nilsson, M., Jordan, A., Turnpenny, J., Hertin, J., Nykvist, B., Russel, D., 2008. The use and non-use of policy appraisal tools in public policy making: An analysis of three European countries and the European Union. Policy Sci. 41, 335–355.

Ogden, A.E., Innes, J.L., 2009. Application of structured decision making to an assessment of climate change vulnerabilities and adaptation options for sustainable forest management. Ecol. Soc. 14.

Ogilvy, T., 2004. Regeneration ecology of broadleaved trees in Caledonian Forest. University of Edinburgh.

Osmond, J., Upton, S., 2012. Growing Our Woodlands in Wales-the 100,000 Hectare Challenge. Institude Welsh Aff. http//www.clickonwales.org/wp-content/uploads/IWAWoodlandsConferenceReport.pdf.

Pe'er, G., Dicks, L., Visconti, P., Arlettaz, R., 2014. EU agricultural reform fails on biodiversity. Science (80-.). 344, 1090–1092.

Petr, M., Boerboom, L.G.J., Ray, D., van der Veen, A., 2015. Adapting Scotland's forests to climate change using an action expiration chart. Environ. Res. Lett. 10, 105005.

Pojar, J., Klinka, K., Meidinger, D., 1987. Biogeoclimatic ecosystem classification in British Columbia. For. Ecol. Manage. 22, 119–154.

Pyatt, D.G., Suarez, J.C., 1997. An ecological site classification for forestry in Great Britain with special reference to Grampian, Scotland. For. Comm.

Pyatt, G., Ray, D., Fletcher, J., 2001. An Ecological Site Classification for Forestry in Great Britain. For. Comm. http//www.forestry.gov.uk/pdf/RIN260.pdf/$FILE/RIN260.pdf.

QGIS Development Team, 2014. QGIS Geographic Information System 2.4. [Computer Software] Open Source Geospatial Found. Proj.

Quine, C., Humphrey, J., Purdy, K., Ray, D., 2002. An Approach to Predicting the Potential Forest Composition and Disturbance Regime for a Highly Modified Landscape: a Pilot Study of Strathdon in the Scottish Highlands. Silva Fenn. 36, 233–247.

Quine, C., White, I., 1994. Using the relationship between rate of tatter and topographic variables to predict site windiness in upland Britain. Forestry 67, 245–256.

R Development Core Team, 2015. R: A language and environment for statistical computing.

Ray, D., 2001. Ecological Site Classification: User's Guide.

Ray, D., Broome, A., 2001. Ecological Site Classification – supporting decisions from the stand to the landscape scale. For. Res. Annu. Report. http//www.forestry.gov.uk/pdf/FR0102esc.pdf/$FILE/FR0102esc.pdf. 40–49.

Ray, D., Wainhouse, D., Webber, J., Gardiner, B., 2008. Impacts of climate change on forests and forestry in Scotland. For. Res. Rep. ….

Read, D.J., Freer-Smith, P.H., Morison, J.I.L., Hanley, N., West, C.C., Snowdon, P., 2009. Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change., The Stationery Office, Edinburgh.

Reynolds, K.M., Thomson, A.J., Köhl, M., Shannon, M.A., Ray, D., Rennolls, K., 2007. Sustainable forestry: from monitoring and modelling to knowledge management and policy science.

Riitters, K., O'neill, R., Jones, K., 1997. Assessing habitat suitability at multiple scales: a landscape-level approach. Biol. Conserv. 3207, 191–202.

Robbins, P., 2003. Beyond Ground Truth: GIS and the Environmental Knowledge of Herders, Professional Foresters, and Other Traditional Communities. Hum. Ecol. 31, 233–253.

Scottish Executive, 2006. The Scottish Forestry Strategy. For. Comm. Scotland, Edinburgh. http//www.forestry.gov.uk/pdf/SFS2006fcfc101.pdf/$FILE/SFS2006fcfc101.pdf.

Scottish Government, 2010. Low Carbon Scotland: Meeting the Emissions Reduction Targets 2010-2022: The Report on Proposals and Policies.

Sing, L., Towers, W., Ellis, J., 2013. Woodland expansion in Scotland : an assessment of the opportunities and constraints using GIS. Scottish For. 67, 18–25.

Slee, B., 2005. From countrysides of production to countrysides of consumption? J. Agric. Sci. 143, 255.

Slee, B., 2007. Social indicators of multifunctional rural land use: The case of forestry in the UK. Agric. Ecosyst. Environ. 120, 31–40.

Smout, T., 2006. The Pinewoods and human use, 1600-1900. Forestry 79, 341–349.

Spracklen, B.D., Lane, J. V., Spracklen, D. V., Williams, N., Kunin, W.E., 2013. Regeneration of native broadleaved species on clearfelled conifer plantations in upland

Britain. For. Ecol. Manage. 310, 204–212.

Staines, B., 1995. The impact of red deer on the regeneration of native pinewoods, in: Our Pinewood Heritage. Forestry Commission, The Royal Society for the Protection of Birds, Scottish Natural Heritage, Inverness, pp. 107–114.

Stewart, A., Edwards, D., Lawrence, A., 2013. Improving the science–policy–practice interface: decision support system uptake and use in the forestry sector in Great Britain. Scand. J. For. Res. 29, 144–153.

Sturrock, R.N., Frankel, S.J., Brown, A. V, Hennon, P.E., Kliejunas, J.T., 2011. Sturrock et al. (2011)_Climate change and forest diseases.pdf. Plant Pathol. 60, 133–149.

Suárez, J.C., Gardiner, B.A., Quine, C.P., 1999. A comparison of three methods for predicting wind speeds in complex forested terrain. Meteorol. Appl. 6, 329–342.

Tanentzap, A.J., Zou, J., Coomes, D.A., 2013. Getting the biggest birch for the bang: restoring and expanding upland birchwoods in the Scottish Highlands by managing red deer. Ecol. Evol. 3, 1890–901.

The Macauley Institute for Soil Research, 1984. Organization and Methods of the 1:250 000 Soil Survey of Scotland. The Macauley Institute for Soil Research, Aberdeen.

Thomas, H.J.D., Paterson, J.S., Metzger, M.J., Sing, L., 2015. Towards a research agenda for woodland expansion in Scotland. For. Ecol. Manage. 349, 149–161.

Towers, W., Schwarz, G., Burton, R., Ray, D., Sing, L., 2006. Possible Opportunities for Future Forest Development in Scotland : A scoping study. Exec. Rep. Submitt. to For. Comm. Scotland. http//www.forestry.gov.uk/pdf/MacaualyEXECUTIVESUMMARY.pdf/$FILE/MacaualyEXECUTIVESUMMARY.pdf.

Urquhart, J., Courtney, P., Slee, B., 2010. Private ownership and public good provision in english woodlands. Small-scale For. 9, 1–20.

van der Horst, D., Gimona, A., 2005. Where new farm woodlands support biodiversity action plans: a spatial multi-criteria analysis. Biol. Conserv. 123, 421–432.

WEAG, 2012. Report of the Woodland Expansion Advisory Group to the Cabinet Secretary for Rural Affairs and Environment, Richard Lochhead, MSP. http://www.forestry.gov.uk/pdf/WEAGFinalReport.pdf/$FILE/WEAGFinalReport.pdf.

Werritty, A., Sugden, D., 2013. Climate change and Scotland: recent trends and impacts. Earth Environ. Sci. Trans. R. Soc. Edinburgh 103, 133–147.

Wilson, S., 2011. Approaches to the future expansion of tree cover on farmland and deer-range in Scotland. WEAG Discuss. Pap. http//www.forestry.gov.uk/website/pdf.nsf/8edb12106b6f634f80256a1500435199/522016ce3ec0192b80257965005e52c2!OpenDocument.

Wilson, S.M., Pyatt, D.G., Malcolm, D.C., Connolly, T., 2001. The use of ground vegetation and humus type as indicators of soil nutrient regime for an ecological site classification of British forests. For. Ecol. Manage. 140, 101–116.

Wilson, S.M., Pyatt, D.G., Ray, D., Malcolm, D.C., Connolly, T., 2005. Indices of soil nitrogen availability for an ecological site classification of British forests. For. Ecol. Manage. 220, 51–65.

Wynne-Jones, S., 2013. Carbon blinkers and policy blindness: The difficulties of "Growing Our Woodland in Wales." Land use policy 32, 250–260.

SUPPLEMENTARY MATERIALS

Publicly Available Spatial Data Sets

Spatial evaluation of woodland creation utilises data obtained from the publicly available ‘Forestry Commission Data Download’ site (FC, 2014c). The following datasets were used in analysis:

- *National Forest Estate - Forest District Boundaries*
  This dataset shows generalised administrative boundaries for all Forestry Commission Forest Districts in Great Britain.

- *FCS Woodland Creation Options RDC*
  This dataset contains spatial data and associated metadata for the woodland creation options approved within the SRDP Rural Development Contracts - Rural Priorities. The options are broken down by option type and claim year.

- *FCS Scottish Forestry Grant Scheme - Sub Compartments*
  This dataset contains spatial data, associated metadata and related component tables of all sub-compartment boundaries lying within approved Scottish Forestry Grant Scheme contracts. The sub-compartment dataset provides information on sub-compartment level operations as well as contract information for each approved scheme.

- *FCS Woodland Grant Scheme 3*
  This dataset contains FCS Woodland Grant Scheme 3 (WGS3) spatial data and associated metadata. This WGS3 dataset provides grant, contract and management information for all Woodland Grant Scheme contracts approved in Scotland between September 1994 and February 2003.

- *FCS Woodland Grant Scheme 2*
  This dataset contains FCS Woodland Grant Scheme 2 (WGS2) spatial data and associated metadata. This WGS2 dataset provides grant, contract and management information for all Woodland Grant Scheme contracts approved in Scotland between June 1991 and September 1994.

- *FCS Woodland Grant Scheme 1*
  This dataset contains FCS Woodland Grant Scheme 1 (WGS1) spatial data and associated metadata. This WGS1 dataset provides grant and contract information for all Woodland Grant Scheme contracts approved in Scotland between June 1988 and June 1991.

- *National Forest Inventory Scotland 2013*
  This file contains 2013 Forestry Commission National Forest Inventory spatial data and associated metadata for Scotland. This dataset includes Interpreted Forest Types (IFTs) for all woodland over 0.5ha and Interpreted Open Area (IOA) information for areas over 0.5ha that are completely surrounded by woodland.

Species selected for modelling

The species selected for modelling are outlined in Table S1. These species represented close to 100% of species planted under the SRDP. We did not investigate minor species such as such as hazel (*Corylus avellana*) and aspen (*Populus tremula*), or conifers such as Lodgepole Pine (*Pinus contorta*) since data availability was insufficient to include these in modelling.

Table S1: Species selected for modelling and composition of SRDP planting

Species	% of SRDP
Betuala pendula (Silver Birch), *Betula pubescens* (Downy Birch)	55%
Picea sitchensis (Sitka Spruce).	15%
Pinus sylvestris (Scots Pine)	10%
Quercus petraea (Sessile Oak)	10%
Fraxinus excelsior (Ash)	5%
Alnus glutinosa (Alder), W1 & W3 Woodland (Wet Woodland)	5%

Species assemblage maps

Species-assemblage suitability maps generated for the comparison of all grant schemes are displayed in Figure S1. Species assemblages are based on species composition for the SRDP (Table S1). These demonstrate the availability and spatial distribution of suitable woodland habitat in Lochaber. The mountainous topography of the region is clearly visible, with most suitable land located in the Great Glen and on the West Coast. The high suitability for *Picea sitchensis* is also evident.

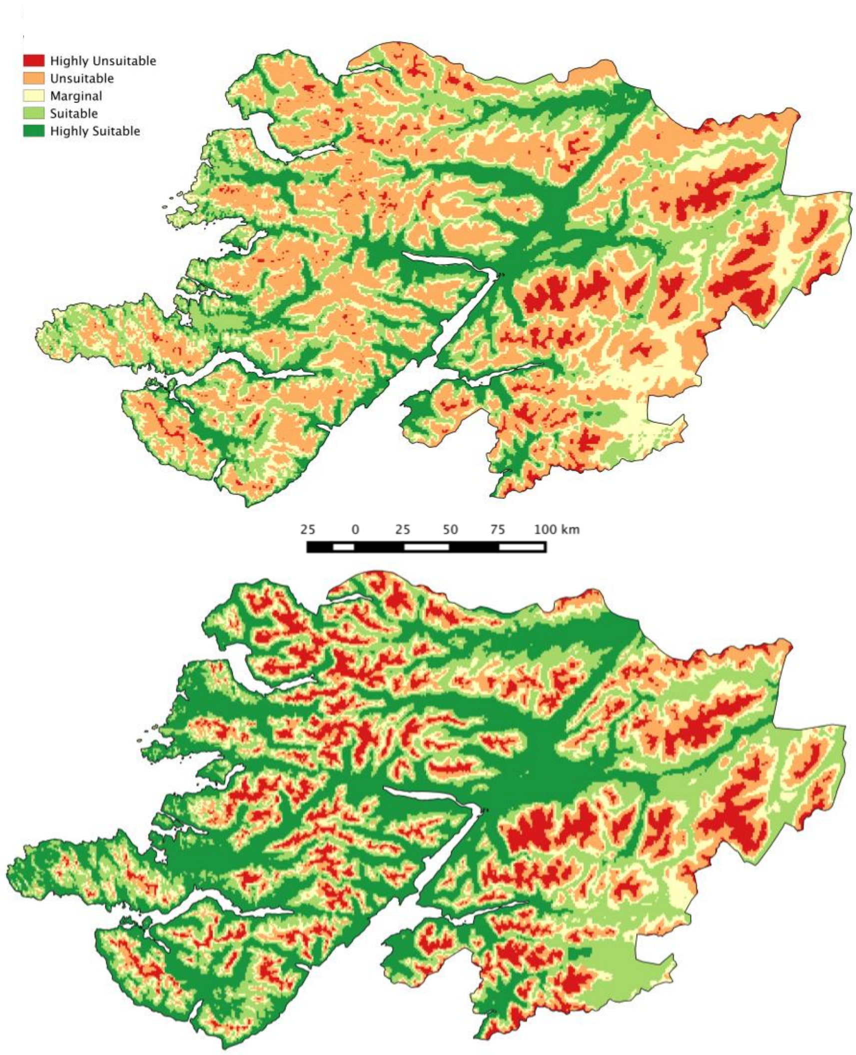


Figure S1: Species-assemblage suitability maps for broadleaf woodland (top) and conifer woodland (bottom). Maps were generated using the ESC methodology with four climatic variables based on the composition of species under the SRDP.

Edaphic Suitability Distributions

The distribution of climatic and edaphic suitability scores is outlined in Figure S2. Overall edaphic suitability was based on the lowest of soil nutrient and soil moisture scores since this represents the limiting factor. Climatic variables display a near-normal distribution of scores skewed towards the right. However, edaphic variables display a flat distribution, with strong clustering of scores at unique values. This arises due to coarse data resolution of soil data. Due to these results, we do not consider edaphic variables to display any significant findings.

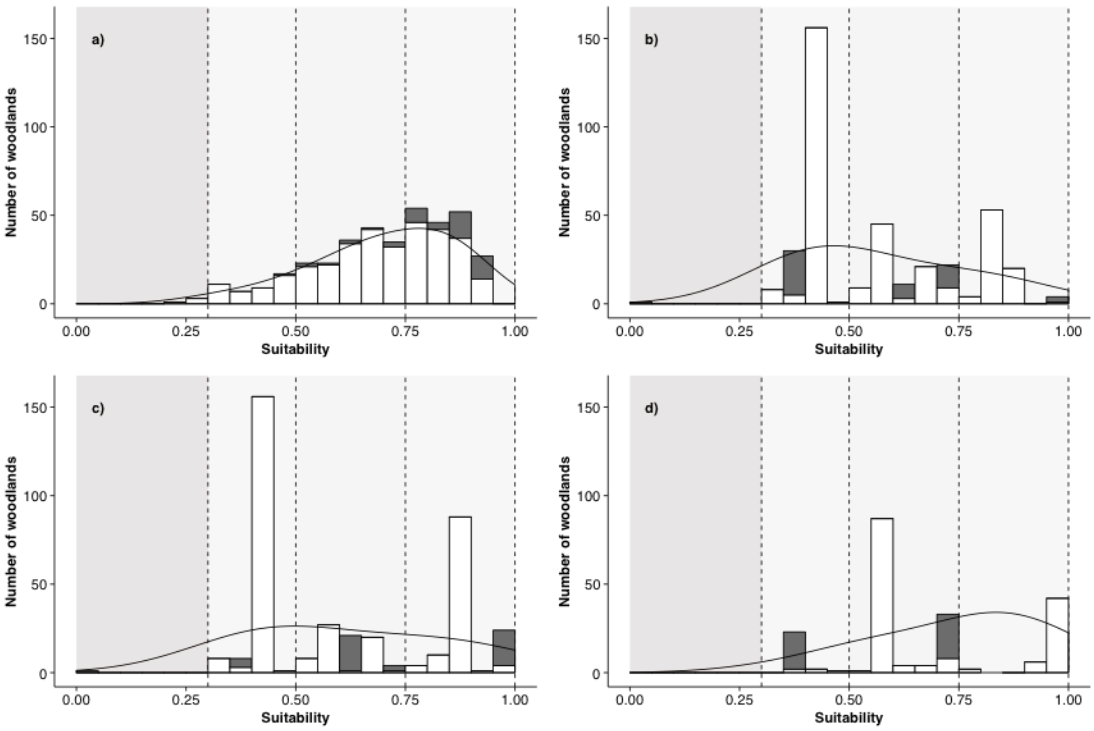


Figure S2: Distribution of suitability scores for woodlands planted 1989-2014 in Lochaber. Graphs represent a) Climatic suitability, b) Combined edaphic suitability, c) Soil Moisture and d) Soil Nutrients. Bars represent the number of woodland sites, while the density curved represents a smoothed distribution of the data. Shaded areas represent suitability categories: Red (0.00-0.30) = Unsuitable, Blue (0.30-0.50) = Marginal, Dark green (0.50-0.75) = Suitable, Light green (0.75-1.00) = Very Suitable.

Figure 1
Click here to download high resolution image

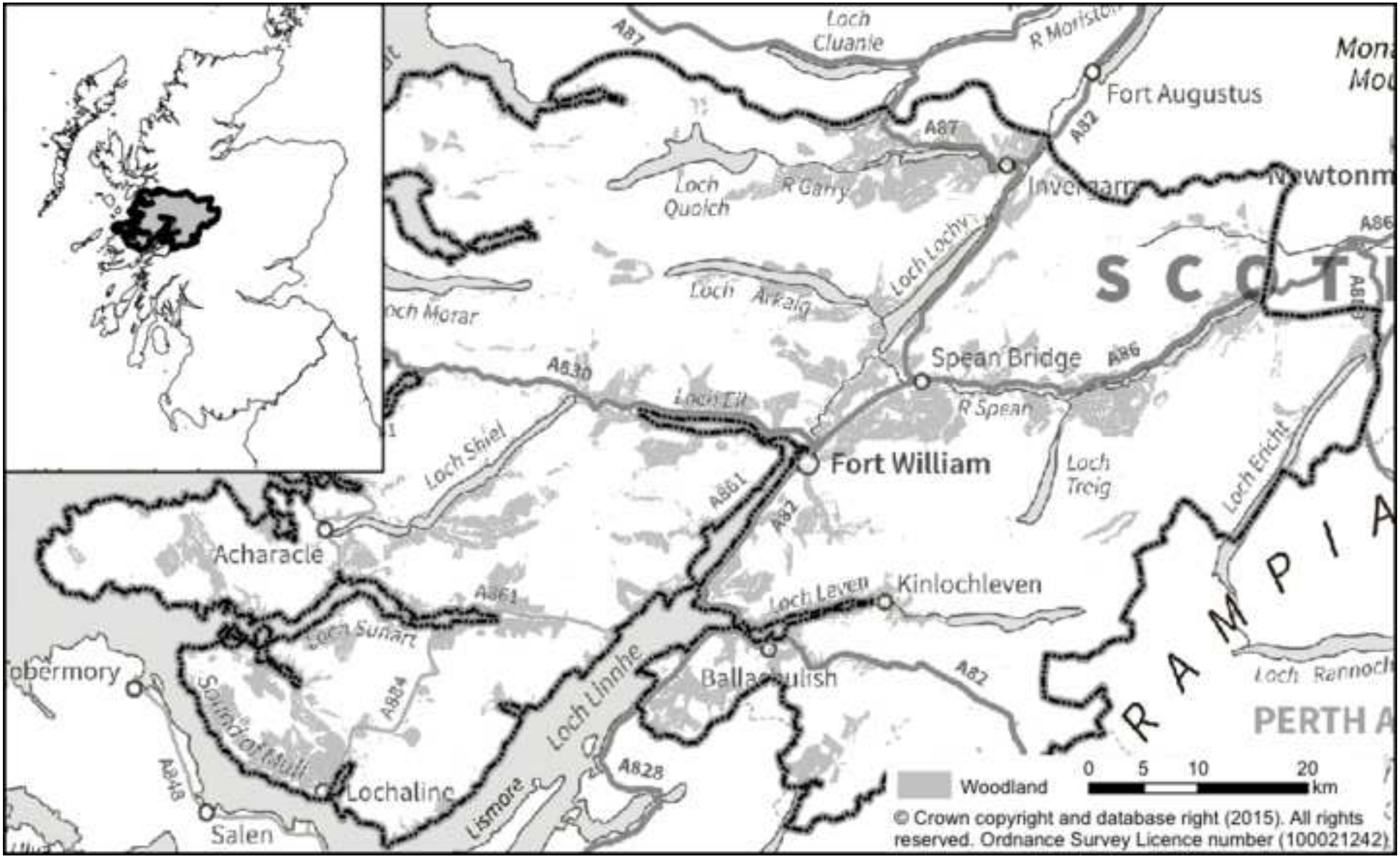


Figure 2
Click here to download high resolution image

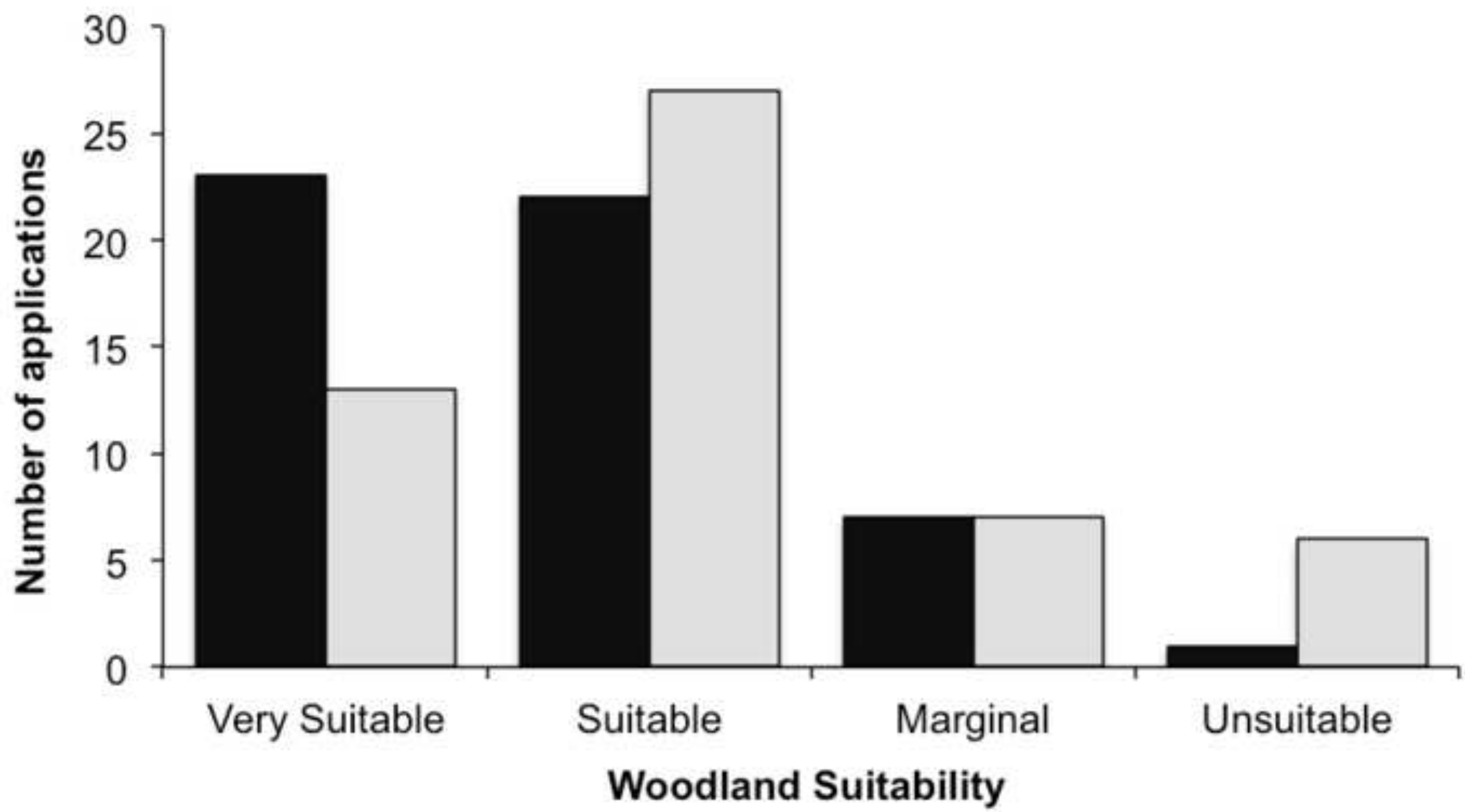


Figure 3
Click here to download high resolution image

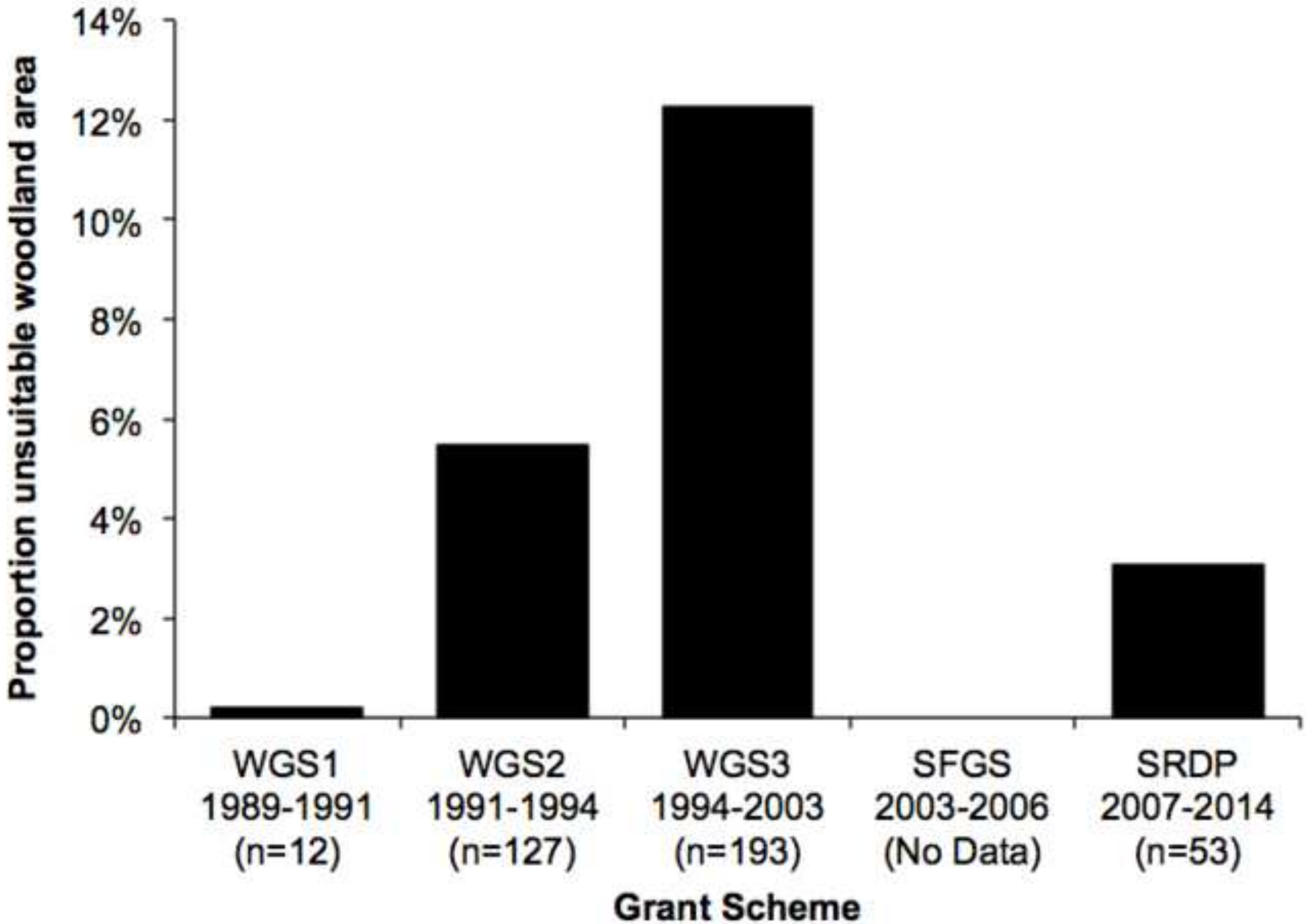


Figure 4
Click here to download high resolution image

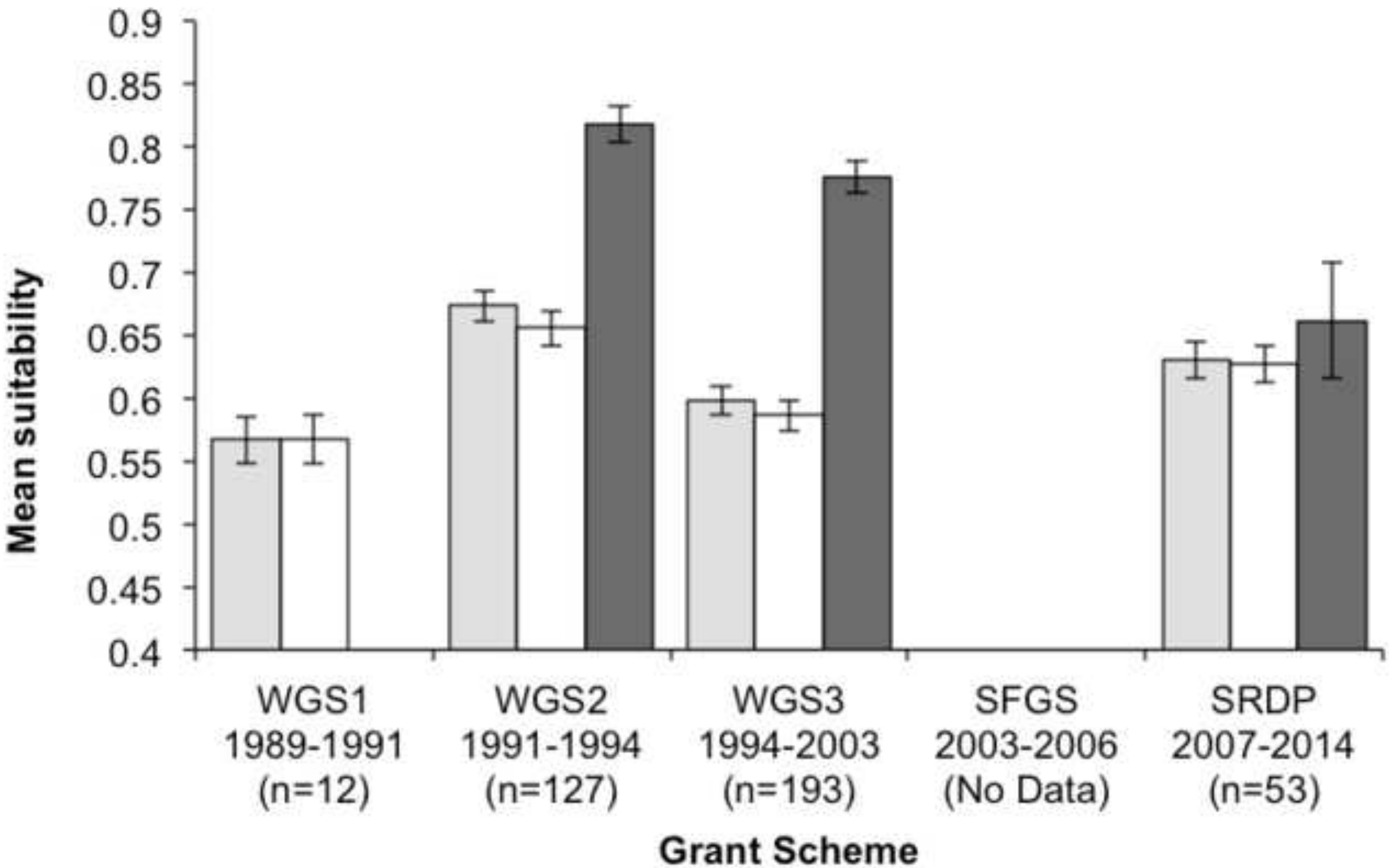


Figure 5

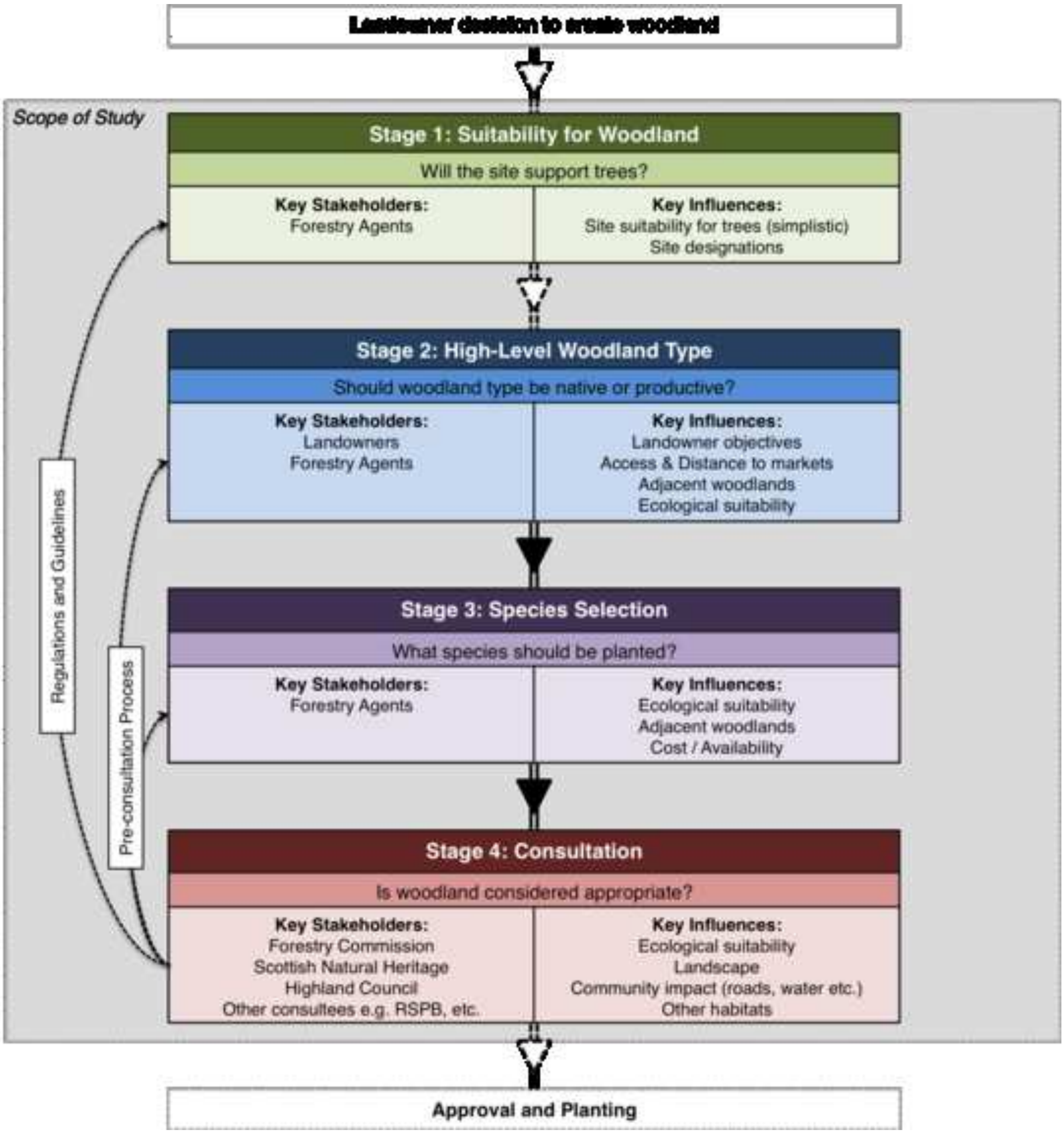

Scope of Study
Stage 1: Suitability for Woodland
Will the site support trees?
Key Stakeholders:
Forestry Agents
Key Influences:
Site suitability for trees (simplistic)
Site designations
Stage 2: High-Level Woodland Type
Should woodland type be native or productive?
Key Stakeholders:
Landowners
Forestry Agents
Key Influences:
Landowner objectives
Access & Distance to markets
Adjacent woodlands
Ecological suitability
Stage 3: Species Selection
What species should be planted?
Key Stakeholders:
Forestry Agents
Key Influences:
Ecological suitability
Adjacent woodlands
Cost / Availability
Stage 4: Consultation
Is woodland considered appropriate?
Key Stakeholders:
Forestry Commission
Scottish Natural Heritage
Highland Council
Other consultees e.g. RSPB, etc.
Key Influences:
Ecological suitability
Landscape
Community impact (roads, water etc.)
Other habitats
Regulations and Guidelines
Pre-consultation Process
Approval and Planting

Figure S1
Click here to download high resolution image

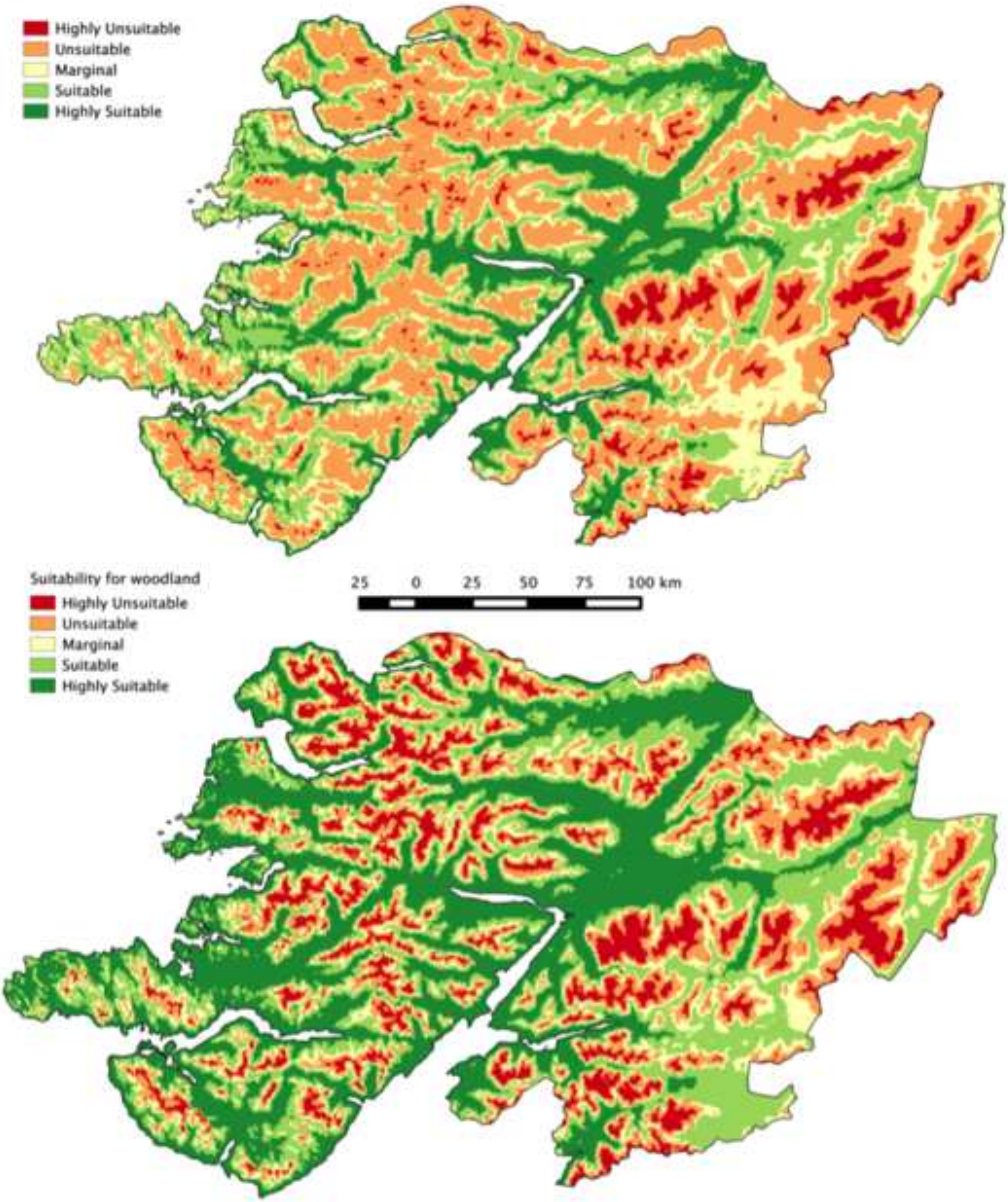
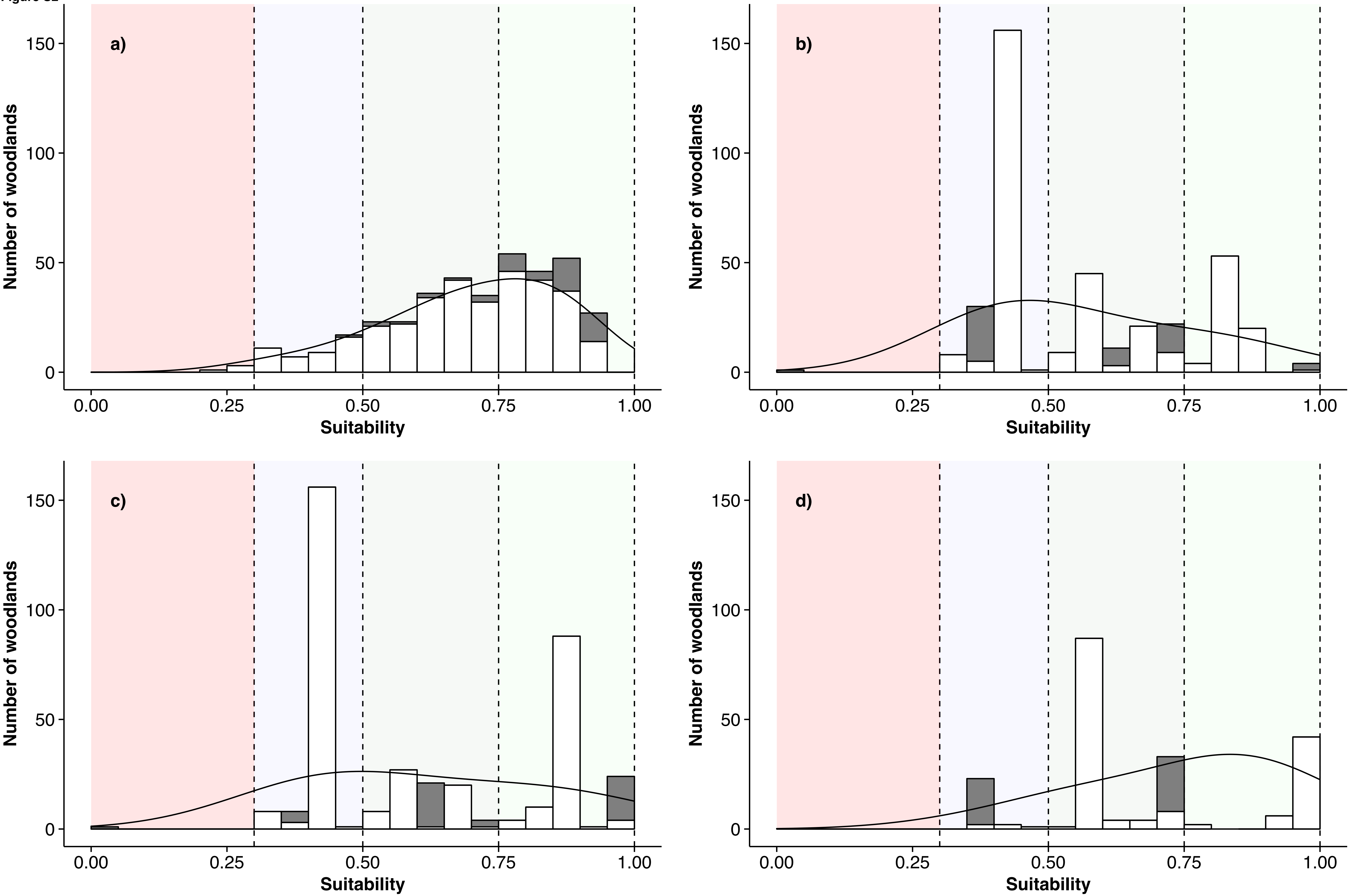


Figure S2



a)
b)
c)
d)
Number of woodlands
Suitability
0
50
100
150
0.00
0.25
0.50
0.75
1.00